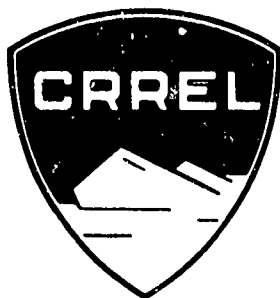


TL 354

AD 747943



Draft Translation 354

# ON DETERMINING THE MELTED WATER CONTENT OF SNOW BY DIELECTRIC MEASUREMENTS

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June 1972

NATIONAL TECHNICAL  
INFORMATION SERVICE

CORPS OF ENGINEERS, U.S. ARMY  
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY  
HANOVER, NEW HAMPSHIRE

DRAFT TRANSLATION 354

ENGLISH TITLE: ON DETERMINING THE MELTED WATER CONTENT OF SNOW BY  
DIELECTRIC MEASUREMENTS

FOREIGN TITLE: ZUR BESTIMMUNG DES SCHMELZWASSERGEHALTES DES SCHNEES  
DURCH DIELEKTRISCHE MESSUNGEN

AUTHOR: Von W. Ambach

SOURCE: Zeitschrift für Gletscherkunde und  
Glazialgeologie (Journal of Glaciology  
and Glacial Geology), vol. 4, no. 1-2,  
p. 1-8, 1958.

Translated by U.S. Joint Publications Research Service for U.S. Army  
Cold Regions Research and Engineering Laboratory, 1972, 7 p.

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W. Ambach

[Current Report from Physical Institute at University of Innsbruck]

[With 3 Illustrations]

Introduction

As is known, the dielectric constant (DC) of a snow-water mixture depends on the mixture ratio. Accordingly, through a determination of the DC, in principle it must be possible to make a statement concerning the melt water content ([Note]: I am grateful to a friendly suggestion from H. Moeker as an inspiration to prepare this report). For a more precise investigation of the relationship, we introduced between the plates of a specially designed plate capacitor snow-water mixtures of varying composition, and the related capacitance values were measured. For a precise capacitance measurement, a bridge substitution technique was utilized. The concept of determining the water content in the manner described has a certain resemblance to identifying the moisture content of soil from dielectric measurements [1, 7].

Preliminary Tests

For attaining optimal measurement conditions, the following testing technique problems had to be studied more closely:

1. The method of capacitance determination and type of capacitor.
2. Effect of electrolytic direct-current resistance of the snow-water mixture on measurement accuracy.
3. Effect of alternating-current loss (effective resistance) as a result of ionic mobility and dielectric polarization [2, 4],
4. The frequency most favorable for the exact bridge synchronizing.

Figure 1 shows the bridge substitution connection which proved quite useful both through its precision and also its convenient application in field operations. The bridge's tuning was done through both potentiometers, whereby in the bridge branch, one can place as desired a comparison capacitor of 500 picofarads or 80 picofarads. The bridge voltage is taken from a spark coil fed by two in-parallel connected flashlight batteries. As a balanced

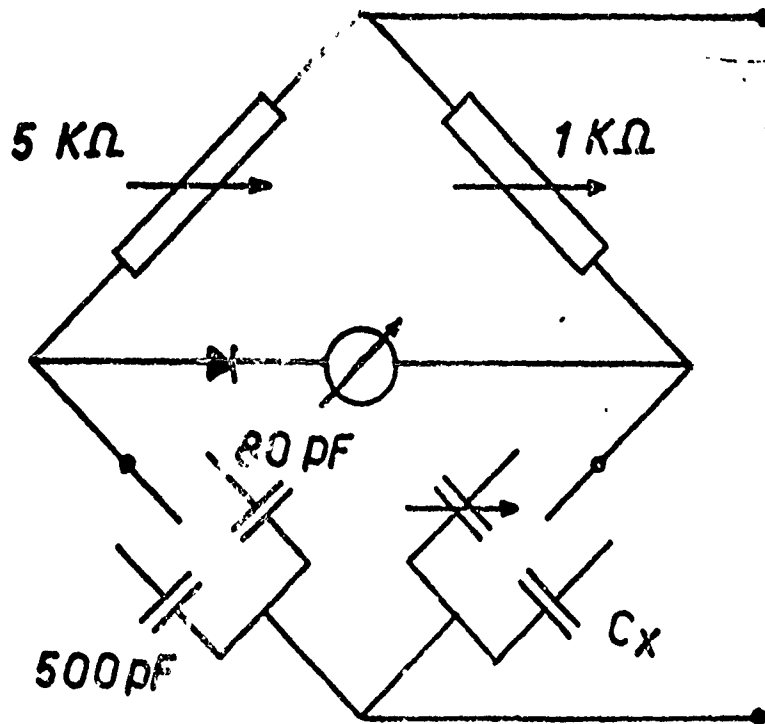


Fig. 1. Circuitry of Bridge Substitution Method Utilized.

bridge zero-setting instrument, use was made of a pointer-type microammeter with lined-up germanium diode to rectify the bridge alternating-current voltage. To determine the capacity  $C_x$  of the plate capacitor filled with the snow-water mixture, this capacitor was connected to the bridge branch and the bridge was synchronized. After that in place of  $C_x$ , a variable air capacitor was installed and this was adjusted until bridge balance had once more been achieved. The directly readable capacitance required for this is then identical with  $C_x$ . Since the spark coil provides no sinusoidal alternating voltage, the methods in which a calculation of the capacitive reactance is necessary are eliminated.

As a measuring capacitor, a plate capacitor was made of four copper sheets (10 X 10 cm and 3 cm plate spacing); this was pushed as a unit into the snow.

Direct-current resistance of a snow-water mixture is very dependent on the mixture's composition; for the measurements mentioned, there thus resulted values ranging from several tens of kilohms to several megohms. As a result of the slight capacitance of the measuring capacitor from about 100 to 300 picofarads, in the audiofrequency range its capacitive reactance re-

mains very high so that the cited direct-current resistance (especially at the low values) in effect causes a short-circuiting of the capacitor. However, this would make a capacitance measurement impossible. To eliminate this direct-current short-circuit, the copper foils of the measuring capacitor were cemented between two plexiglas plates. In order to impart greater stability to the plates, they were supported by two plexiglas strips. In air, the capacitor has a capacitance of 20 picofarads. Since capacity changes occur only in the measuring capacitor, the connecting cable had to be made as low in capacity as possible with about 2 meters length in order to attain the highest possible sensitivity. Through the addition of a coaxial cable with inserted copper wire (0.3 mm diameter), a cable capacity of 40 picofarads was attained. It is certainly possible to further reduce this value in half by the use of commercial low-capacity cable.

However, with the direct-current type of insulation, one still fails to attain an ideal phase angle of the snow capacitor. Through the alternating voltage, there specifically occur additional losses in each dielectric, which (losses) reduce the accuracy of the capacity measurement. Through phase compensation by means of a resistor connected in-parallel to the comparison capacitor, this effect can be eliminated only if the dissipative (loss) resistance remains very high as compared with capacitive reactance. Accordingly it was necessary to study more closely the values which are able to affect the phase angle of the snow capacitor.

#### Studies of Frequency Response of Capacity and Phase (Loss) Angle

J. Granier [3] using pure ice which had been frozen from twice-distilled water has already measured a strong frequency response of the dielectric constant and of phase angle between 6,  $7 \cdot 10^6$  and 4, 3 Hz. J. Errera [5] has also found a pronounced frequency response of ice's dielectric constant in the range from  $10^3$  to  $10^4$  Hz. From theoretical considerations [2], it follows that a frequency response of phase angle is simultaneously linked with a frequency dependent dielectric constant. This frequency curve (response) is also demonstrated clearly by actual measurements of snow-water mixtures and at the same time thereby confirm the measured frequency dependence of the DC. In Fig. 2b, the loss resistance and in Fig. 2c,  $R \omega C$ , the cotangent of phase angle, has been plotted vs. logarithm of frequency. Between  $10^4$  and  $10^5$  Hz, both values have a minimum. Hence the tuning accuracy is the least in this frequency range.

The increase in capacitance at audiofrequencies (Fig. 2a) favors the measurements in the lower frequency range because the lesser contribution of frequency is partly compensated by an augmented total of capacitance. To be sure, capacitance increases only by a factor of 2 to 3 if frequency drops from  $10^5$  to  $10^3$  Hz, hence by 2 powers of 10. The question as to whether water content had be determined more precisely at low or high frequencies does remain of decisive importance. In this connection, investigations indicate that the difference in the capacitance value evoked by a certain change in the mixture ratio is greater at low frequencies ( $10^3$  Hz) than at high frequencies ( $10^5$  Hz); however, in the frequency range studied, the percentual capacitance variation remains about the same.

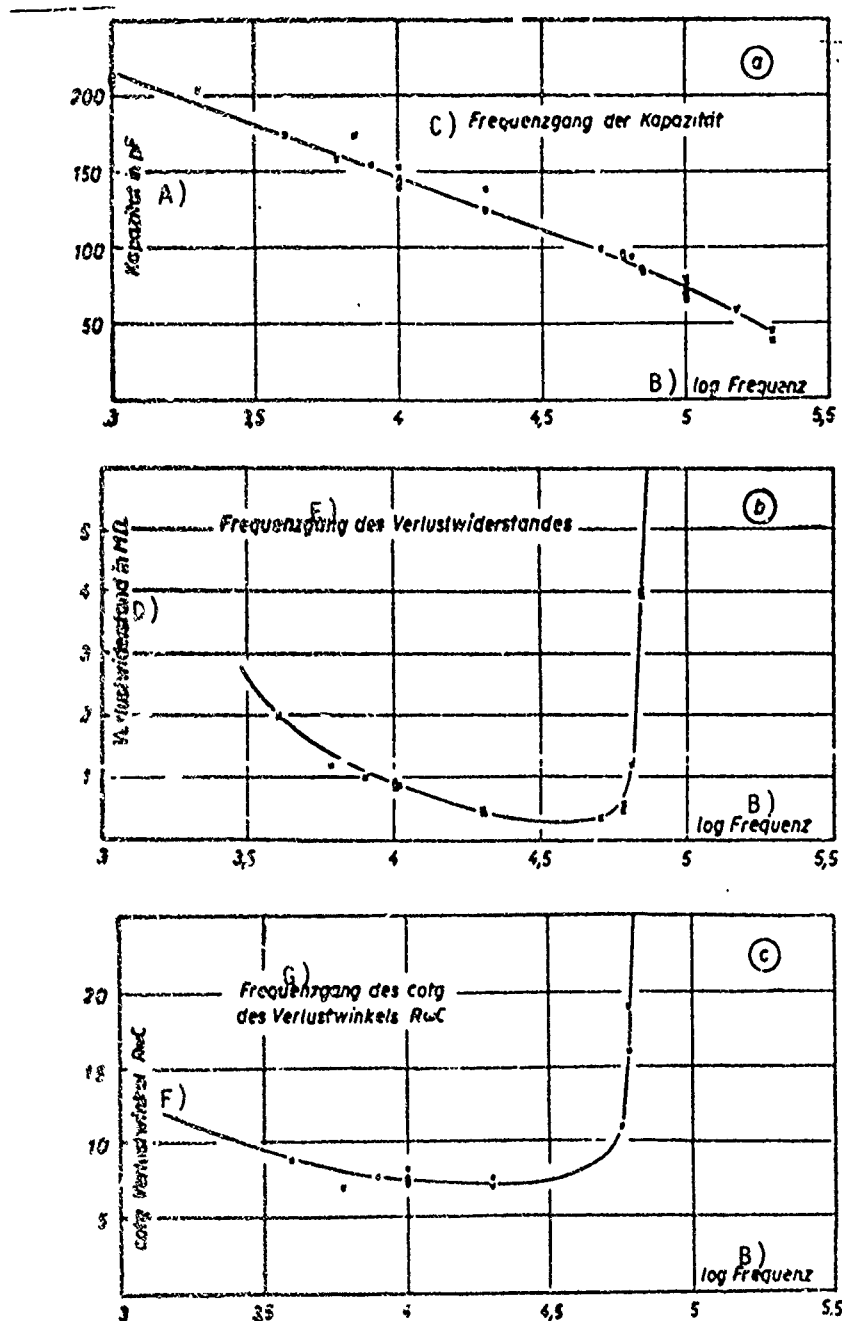


Fig. 2. Frequency Curves of a) capacitance; b) loss resistance; and c) cotangent of phase angle of capacitor filled with wet snow sample with direct-current type insulation. Key: A. capacitance, pF; B. logarithm of frequency; C. capacitance frequency curve. D. loss resistance in MΩ; E. frequency curve of loss resistance. F. cotangent of phase angle  $R\omega C$ ; and G. frequency curve of phase angle  $R\omega C$  cotangent.

In this context, Table 1 provides an overall idea of the comparative measurements. These measurements and the frequency curves shown in Fig. 2a, 2b and 2c were not conducted with the plexiglas capacitor but with a steel plate capacitor, the plates of which had been covered experimentally with a nylon skin for direct-current insulation. The utilization of a capacitor without nylon skin naturally enlarges the phase angle; in spite of this, capacitance measurements could still be performed in the laboratory with adequate accuracy at frequencies which are not too low. The fact that without a nylon covering, other capacitances occur is insignificant because it is merely a question of relative capacitance variations.

Table 1

Several Comparative Measurements of Capacitance Variation of a Snow-Packed Capacitor

	Frequency	Capacitance C prior to water addition	Capacitance C after water addition	C'-C	C'	Remarks
Sample 1	$10^3$ Hz	335 pf	500 pf	165 pf	1.5	With nylon skin
	$10^4$ Hz	170 pf	390 pf	220 pf	2.3	
	$10^5$ Hz	84 pf	175 pf	91 pf	2.1	
Sample 2	$10^3$ Hz	410 pf	690 pf	280 pf	1.7	With nylon skin
	$10^5$ Hz	150 pf	280 pf	130 pf	1.9	
Sample 3	$10^4$ Hz	470 pf	1300 pf	830 pf	2.8	Without nylon skin
	$10^5$ Hz	150 pf	470 pf	320 pf	3.1	

Calibration of the Measuring Capacitor

It is probably inadmissible to calibrate the described measuring device empirically because the relationship between type of snow and water content is of too complex a nature to permit us to develop a mathematical relationship between these values. Several calibration results which have been obtained with the plexiglas capacitor are already available. For this purpose, snow-water mixtures of a known composition were prepared. Figure 3 reflects a calibration curve derived in such a way. It can be observed that capacitance increases linearly with melt water content. As the average from several calibrations, for an increase in melt water of 3% by volume, there results a capacitance rise of 88 pf. We have yet to investigate whether it is preferable to determine the water content of the given sample by a calorimetric method. Worthy of mentioning are the observations made by Person [7] to the effect that in moist sand samples, a linear relationship occurs between the variation in the DC and  $\epsilon'$  of the water content, and ... the calibration curve depends on the grain size of the material applied. A similar dependence of the calibration curve on type of snow (grain size) will probably also occur in the snow studies. Extensive additional field projects must be undertaken to clarify these relationships.

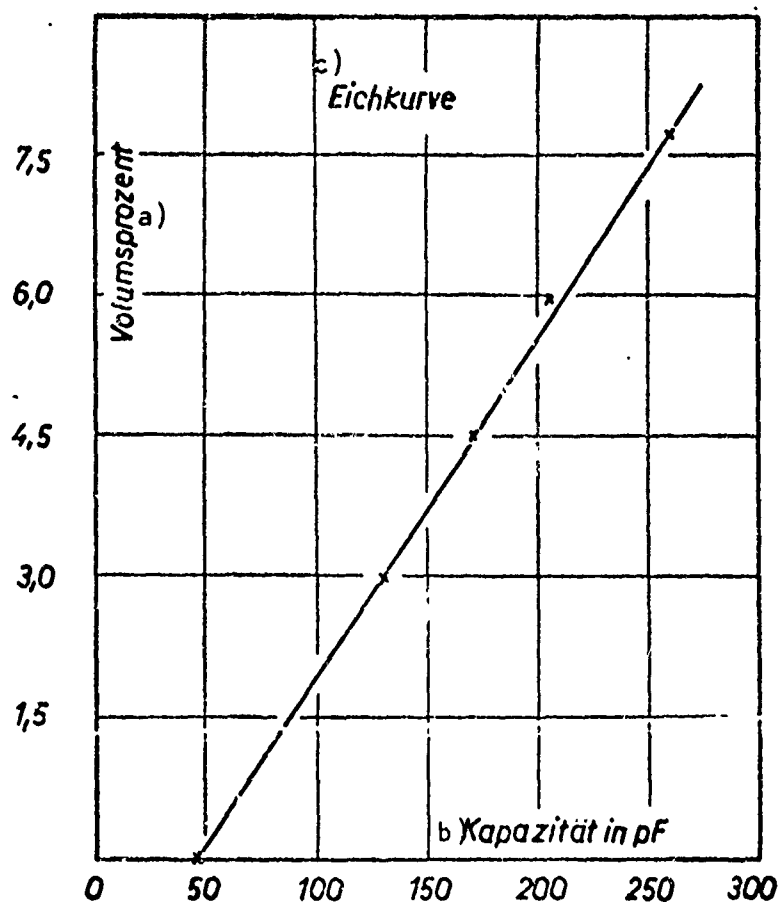


Fig. 3. Capacitance Change of a Plate Capacitor Caused by Melt Water Content of the Snow Sample.

Key: a. percent by volume; b. capacitance in pf; and c. calibration curve.

#### Discussion of the Experiences Gained

We should first of all discuss which frequency range is best suited for the measurements of the melt water content.

The audiofrequencies have the advantage that the difference between capacitance with dry snow and with wet snow is greater; moreover, the capacitances' absolute values are higher. However, in the application of low frequencies, it has to be taken into account that capacitance is dependent not only on water content but also on density of packing (grain size) of dry snow, as can be inferred from the measurements made by J. Granier [3] and J. Errera [5]. The cited authors show that in the range of low frequencies (below 5 KHz), ice's dielectric constant increases sharply. Thereby, density would appear in the calibration curve as a parameter. Moreover, in this frequency range a temperature dependence of the DC might also be anticipated.



The measurements indicated permit us to conclude that at high frequencies ( $10^5$  to  $10^6$  Hz), the capacitance's dependence on dry snow's density remains very slight and that no temperature dependence of DC occurs with dry material. The disadvantage of these frequencies lies in the slight capacitance change at varying water content as contrasted with the values in the audiofrequency range.

The final results on the usefulness of the method described and its limitations can not be announced until after the completion of the field operations at Hintereisferner (Oetzaler Alps).

For the support of these studies, I thank Prof. Dr. R. Steinmaurer, the Board of Directors at the Physical Institute at the University of Innsbruck, and Lecturer Dr. J. Kolb.

### Summary

By measuring the capacity of a plate condenser filled with a mixture of snow and water, one is able to determine the water content of this mixture. Capacity is measured with a bridge in which the condenser to be measured is substituted. The condenser's plates are sealed in plexiglas so as to insulate them for direct current. The experiments showed the capacity and the loss (phase) angle to be a function of frequency in the range of  $10^3$  to  $10^5$  Hz. To date, measurements indicate a linear increase in capacity by approximately 10 pf for a 1% by volume increase in water content. Original capacity of dry snow was 50 pf.

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